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Engaging stakeholders across a socio-environmentally diverse network of water research sites in North and South America

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A R T I C L E I N F O

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A B S T R A C T

Maintaining and restoring freshwater ecosystem services in the face of local and global change requires adaptive research that effectively engages stakeholders. However, there is a lack of understanding and consensus in the research community regarding where, when, and which stakeholders should be engaged and what kind of researcher should do the engaging (e.g., physical, ecological, or social scientists). This paper explores stakeholder engagement across a developing network of aquatic research sites in North and South America with wide ranging

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cultural norms, social values, resource management paradigms, and eco-physical conditions. With seven sites in six countries, we found different degrees of engagement were explained by differences in the interests of the stakeholders given the history and perceived urgency of water resource problems as well as differences in the capacities of the site teams to effectively engage given their expertise and resources. We categorized engagement activities and applied Hurlbert and Gupta's split ladder of participation to better understand site differences and distill lessons learned for planning comparative socio-hydrological research and systematic evaluations of the effectiveness of stakeholder engagement approaches. We recommend research networks practice deliberate engagement of stakeholders that adaptively accounts for variations and changes in local socio-hydrologic conditions. This, in turn, requires further efforts to foster the development of well-integrated research teams that attract and retain researchers from multiple social science disciplines and enable training on effective engagement strategies for diverse conditions.

1. Introduction

Climate change and other human activities are exacerbating water resource management challenges in many communities by increasing droughts and floods and accelerating water quality degradation with polluted runoff (Sivapalan et al., 2012; Xu et al., 2018). To better address these and other complex socio-environmental problems, there has been a global shift towards participatory approaches to resource management and decision making (Megdal et al., 2017; Sterling et al., 2017; Xue et al., 2015). With this shift in management paradigm, there have been calls for researchers to increase stakeholder (SH) engagement and participation in environmental research as well (Fischer et al., 2015; Stafford et al., 2010). Proponents argue that participatory research (research that includes non-scientists) promotes collaboration amongst multiple SH groups, greater trust among SHs, and eventually more durable and equitable solutions to socio-environmental challenges (Blackstock et al., 2007; Tengö et al., 2014; Trimble and Berkes, 2013). Reported benefits of increased participation in research include (1) generation of results directly relevant to society and decision makers, (2) enhanced communication of data and results to broader audiences, (3) increased stakeholder understanding of and trust in science (4) active citizenship, and (5) increasing adaptive capacity (Barreteau et al., 2010; Blackstock et al., 2007). However, these positive outcomes are not guaranteed and research teams face many challenges in incorporating non-scientists into the research process.

Poor outcomes to participatory processes are often attributed to poor planning and inadequate evaluation. This is in part due to a lack of understanding amongst researchers increasingly expected to engage on how to design, implement, and evaluate participatory research (Blackstock et al., 2007). Due to the added complexity, participatory research is associated with higher monetary, administrative, and opportunity costs and longer timelines for achieving results when compared to similar 'experts only' projects (von Korff et al., 2010; Kueffer et al., 2012; Luyet et al., 2012). Many participatory approaches require facilitators who spend considerable time with the community, understanding their concerns and building trust. Due to limitations in time and budgets, researchers have to make trade-offs between engaging SHs and achieving other research goals. All these factors (insufficient guidance and expertise, high costs, and long timelines) can lead to poor execution that disillusions participants and risks their future participation (Blackstock et al., 2007; von Korff et al., 2010; Luyet et al., 2012). This uncertainty raises questions for researchers of what method(s) of SH interaction to use, when, and where. These determinations can be difficult to make for new research sites and/or for researchers new to engaging SHs.

Stakeholder engagement around water resources poses additional complications for aquatic scientists. Water resources have multiple uses and watersheds often cross governance boundaries. Aquatic ecosystems, therefore, tend to have SHs operating at multiple spatial scales and with varying degrees of knowledge and empowerment (e.g., state vs. municipal government, up vs. downstream users, onsite users vs. offsite landowners). The challenges and complexities associated with engaging SHs in aquatic ecosystem research requires careful planning, implementation and evaluation on the part of the research team to ensure that SH willingness to participate in research and other participatory processes is maintained and improved (Barreteau et al., 2010; Xu et al., 2018). Without this planning, SH disillusionment, a loss of trust and/or interest in participatory processes over time, can result from the exclusion of already marginalized groups, empowerment of already influential SHs, or involvement of SHs that are not representative of the community (Blackstock et al., 2007; Luyet et al., 2012; Tengö et al., 2014). Unclear or disputed objectives, unmet expectations, and lack of sufficient control over the project outcomes can also lead to SH disillusionment and reluctance to accept project outcomes (Barreteau et al., 2010; von Korff et al., 2010; Reed, 2008). Unsuccessful engagement can increase community conflict and is not only detrimental to the current project but may also negatively impact SH willingness to participate in future participatory projects. These unintended outcomes necessitate a need to understand how to effectively engage diverse populations in scientific research that informs societal issues (Fischer et al., 2015; National Academies of Sciences, Engineering, and Medicine, 2017).

Coordinated research networks present an opportunity to improve understanding of what stakeholder engagement strategies work under what conditions. However, the need for replication and cross-site comparison has to be balanced with the principle that willingness to participate is a public good that researchers are responsible for maintaining through site specific actions that build trust (Barreteau et al., 2010). Given this tension, we argue that research networks interested in engaging SHs in aquatic research need to wade in carefully if they want to realize the benefits of participation while avoiding the pitfalls. How should research networks balance recommendations for site-specific engagement with the need to provide systematic understanding through replicated, cross-site research? We analyze how this tension was navigated during a 5+ year initiative to establish a coordinated research network to examine climate and other risks to freshwater ecosystem services (ES) across diverse research sites in South and North America. The

Sensing the Americas' Freshwater Ecosystem Risk (SAFER) sites represent a set of 'most different cases' meaning that they vary significantly in terms of culture and patterns of governance, history of participation at the site, and the salience of threats to water resources amongst SHs (Thomas, 2011). In addition, there were variations in the disciplinary expertise of site teams, resources for engagement, including time and funding levels relative to the size of the watershed, and the extent of interactions between researchers and SHs prior to SAFER. These differences in the capacity for SH engagement are also reflected in outcomes.

Drawing on the literature on participation and SH engagement, we comparatively analyze these diverse cases, first categorizing engagement activities by a set of commonly-used degrees of participation (Arnstein, 1969; Blackstock et al., 2007; Luyet et al., 2012). To explain differences across the network, we utilize the more nuanced split ladder of participation (Hurlbert and Gupta, 2015) to visualize, compare, and contrast research sites. The split ladder is a diagnostic tool that enables teams to plan for appropriate engagement by assessing when and if participation is likely to be productive or beneficial at a given site. It highlights elements such as the existing levels of trust, the complexity of the socio-hydrologic conditions, and the problem solving capacity of stakeholders and research teams. Using this tool, we add to a growing body of research that questions normative assumptions that participation is an end in and of itself, and more is better (Hurlbert and Gupta, 2015; Sterling et al., 2017; Young et al., 2013). Instead, we explore how the socio-environmental conditions affect decisions about engagement approaches at the site and network scale. Finally, we discuss internal and external barriers to participatory engagement and lessons learned for responsibly advancing participatory cross-site research that improves understanding of socio-hydrologic systems.

2. Methods

2.1. Research network description

The SAFER project created a collaborative research network of physical, ecological, and social scientists with the broad goal of improving understanding of risks to aquatic ES across a broad socio-environmental gradient of sites in South and North America. SAFER researchers hypothesized that climate change-related alterations in the hydrological cycle interact, at times in unexpected ways, with multiple human stressors within the watershed to change aquatic ecosystem conditions and alter the ES derived from them (Fig. 1). SAFER had two stated objectives, to (1) employ freshwater ecosystems as "sentinels" of multiple interacting stressors and assess risks to ES in the Americas and (2) determine management and mitigation strategies which are both technically and economically feasible as well as culturally acceptable. This research involved deploying sensors to capture current data, gathering historical data, developing models, and other research tasks that could be readily replicated across watersheds. It also required

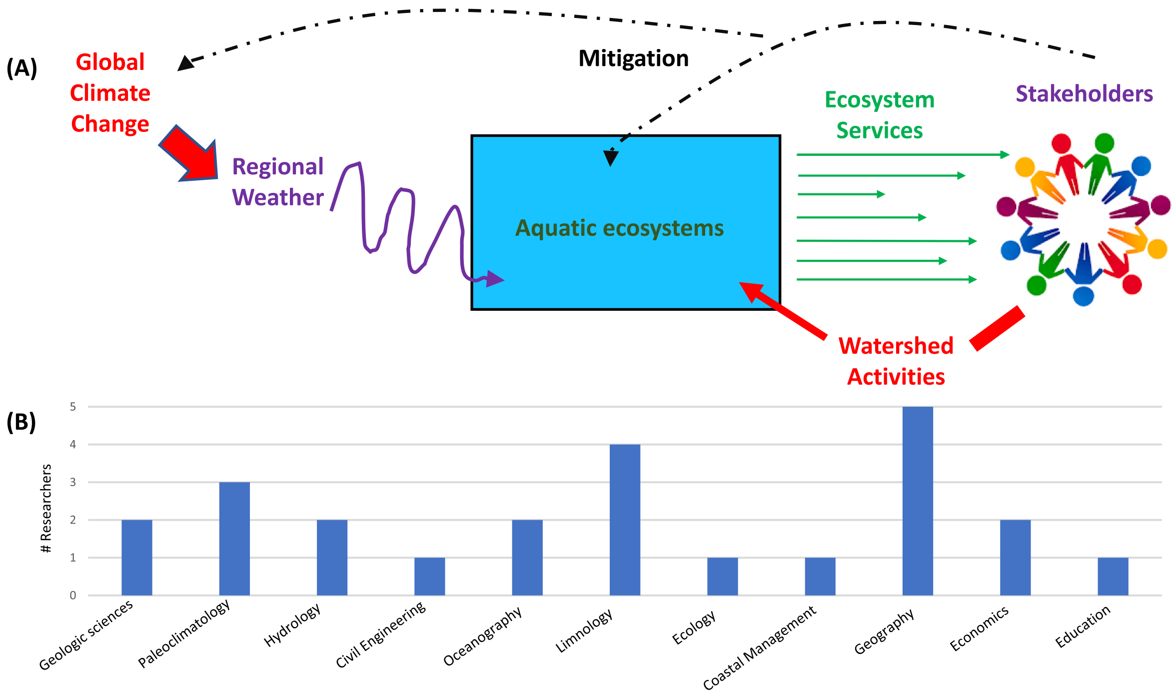

Fig. 1. (a) Conceptual model of socio-hydrologic system hypothesized by SAFER researchers for guiding research and risk assessment. Solid red arrows indicate anthropogenic stressors, purple arrow indicates weather patterns through which climate change is mediated, green arrows represent the myriad of services people receive from aquatic ecosystems, and black dashed arrows represent current and future feedbacks from management and mitigation actions. (b) number of researcher participants from different scientific disciplines across the SAFER network at the project conclusion. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

researchers to engage with SHs in order to understand how they perceive and value ES. Participatory methodologies, however, were not replicable across sites for reasons revealed through the case study analysis presented.

The network was initiated in 2012 with seven watersheds that included large river basins, lakes, reservoirs, and coastal lagoons from 35°S to 45°N latitude with climates ranging from tropical to sub-polar and humid to semi-arid and diverse socioeconomic and cultural conditions (Table 1 and Appendix A). The research sites were assembled largely from pre-existing research sites and networks (e.g., Global Lake Ecological Observatory Network) with some new research initiated in remote areas in Chilean Patagonia to extend the gradient of socio-environmental conditions studied. The logistical challenges of employing methodologies that require SH participation across research sites were not considered at the outset but rather discovered over the course of the project. From 2012 to 2018 researchers from across sites gathered 1–2 times per year to exchange ideas, data, and engagement practices, coordinate and advance analyses, receive cross-disciplinary training, and generally familiarize themselves with each other's research and sites. Multi-disciplinary research occurring within the network included paleolimnology & climatology (Correa-Metrio et al., 2016; Restrepo et al., 2019; Velez et al., 2014), climate variability (Aliaga et al., 2017; Brendel et al., 2017), limnology (Alfonso et al., 2015; Bohn et al., 2016), ecology (Meerhoff et al., 2013; Rodríguez-Gallego et al., 2017), hydrobiology (Villamizar et al., 2014), watershed modeling (Hoyos et al., 2019; Jepsen et al., 2018), and ecosystem service risk assessments (Harmon et al., 2018; Zilio et al., 2017). The nature of research questions and methodologies pursued at the site-scale was influenced by known data needs, expertise of the site team, and in some cases, interests of local SHs. Each site team identified important ES and current and future threats to those services (see Table 1 and Harmon et al. (2018) with SH input where possible.

2.2. Split ladder analysis

We used surveys of network researchers, participant observation, and published literature to report, compare and contrast SH engagement in research across the seven original SAFER sites. The goal was to understand the socio-hydrologic context at each site and establish a baseline to facilitate planning for comparative research that engages SHs across diverse sites in the future. We collaboratively developed a questionnaire on the practice of SH engagement during a SAFER project meeting in 2016 (see Table B1) that was subsequently completed by each site team, in some cases with input from external collaborators that engage more directly with SHs. Follow-up questions were circulated to all SAFER researchers with SurveyMonkey near the close of the project in November 2018. Researcher responses were used along with peer-reviewed literature to contextualize each site by describing the ecosystem and services provided, the climate and how it is changing, the primary economic activities in the watershed, and their impacts on local water resources (Table 1). We then summarized the SH engagement at each site prior to and during the SAFER project and identified the degree to which the site teams engaged different types of SHs using the widely adopted "ladder of participation" (Arnstein, 1969; Barreteau et al., 2010; Luyet et al., 2012). The specific definitions of degrees of engagement used for this analysis are given in Table 2. SHs are defined from the perspective of this research to be any institution, group or individual that is responsible for, interested in, or impacted by the aquatic environment(s) under study. The research teams at each site identified relevant SHs at the start of the project

Table 1
Site characteristics for SAFER research sites, Lago Paloma Complex (LPC), La Salada (LS), Sauce Grande Basin (SGB), Laguna de Rocha (LdR), Ciénaga Grande de Santa Marta (CGSM), San Joaquin River (SJR), and Muskoka River Watershed (MRW). Adjusted Human Water Stress (aHWS) is calculated in Harmon et al. (2018).

	LPC Chile	LS Argentina	SGB Argentina	LdR Uruguay	CGSM Colombia	SJR USA	MRW Canada
Latitude Longitude	45°48′S 72°33′W	39°27′S 62°42′W	38°29′S 61°47′W	34°35′S 54°17′W	10°53′N 74°24′W	37°44′N 119°10′W	45°13′N 79°16′W
Aquatic Ecosystem (s)	River, lakes, streams	Lake	River, reservoir, lake	Coastal lagoon	Coastal lagoon	River, reservoirs	River, lakes, streams
WS area (km^2)	1500	9	4160	1312	4300	40,400	5600
Climate	Temperate /boreal	Semi-arid	Temperate	Sub-tropical	Tropical	Semi-arid	Temperate /boreal
Precipitation ($cm\ yr^{-1}$)	82–200	52	80	107	45–270	15–170	103
Climate projections	Less precip; more variability	Warmer temps; more variability	Warmer temps; more variability	Sea level rise; more storm surge	Less precip; sea level rise	Less snowpack; more variability	Warmer temps; more variability
Pop. Density (ppl. km^{-2})	<0.2	780	6	22	70	100	15
aHWS (0–1)	0.60	0.55	0.65	0.65	0.75	0.35	0.35
Major economic uses	Tourism; ranching; firewood	Tourism; agriculture	Agriculture; tourism	Ranching; fishing; tourism; agriculture	Fishing; agriculture; ranching	Agriculture; hydro-power; tourism	Tourism
Threats to ES	Deforestation; invasives; hydro-power	Diversion; eutrophication; erosion	Drought; development	Erosion; eutrophication; development	Diversion; eutrophication; salinization	Diversion; drought; warming	Develop-ment; salinization; flooding

Table 2
Summary of SH engagement activities by SAFER researchers (X) and their collaborators (C) across sites.

Planning process	LPC	LS	SGB	LdR	CG SM	SJR	MRW
Formal SH identification conducted		X	X	X	C	X	X
Pre-planned process for engaging SHs	X			X	C		
Evaluation(s) of engagement by SHs conducted				X	C		
1. Informative: researchers share research plans and/or findings with SHs through written and/or oral communications							
Informal discussions with SHs	X	X	X	X	X	X	X
Distribution of informative material to SHs	X			X	C	X	
Educational talks/seminars		X		X	C	X	X
Other informative engagement	X	X	X		X		
2. Consultative: researchers collect perspectives, opinions, suggestions and/or data about the ecosystem and/or research activities from SHs through surveys, focus groups, public meetings, interviews or other formal or informal means							
Ecosystem risk/services defined with SHs			X	X			C
SHs surveyed	C	X	X	X			
Focus group/workshop meetings	X	X	X	X			C
Numeric dataset(s) provided by SH(s)				X		X	
Local knowledge informs project design	X	X	X	X	X	X	X
3. Collaborative: Stakeholders participate in one or more aspects of the research process including planning, implementation, and evaluation phases							
SHs involved in project planning		X		X			
Citizen science/monitoring program		X		X			C
Other collaborative activities				X	X	X	X
4. Co-decisive: Researchers and SHs seek consensus on one or more aspects of the research agenda. SHs have some degree of decision-making authority over the research process							
Research agenda by consensus with SHs		X			C		
Adaptive management practiced at site		X		X	C		
Co-management of the ecosystem				X	C		
Adaptive governance practiced at site				X			

(if not before). At Laguna de Rocha (Uruguay) and La Salada (Argentina), SHs engaged prior to SAFER participated in identification of additional SHs. For this report, site research teams and individuals self-reported the degree to which they engaged different SHs relevant to their site and the barriers encountered. SH evaluations of engagement efforts have not yet been systematically conducted, a shortcoming in project design and implementation discussed below.

To compare and contrast the conditions for engagement and enable informed decisions about the transferability of SH-dependent methodologies and practices, we utilized the "split ladder of participation" (Hurlbert and Gupta, 2015). The split ladder creates 4 quadrants based on trust (horizontal axis) and participation (vertical axis) where the rungs on the original ladder of participation run from the lower left quadrant 1 (low participation, low trust) to the upper right quadrant 3 (high participation, high trust) (see Fig. 2 in Hurlbert and Gupta, 2015). To this, the split ladder adds the lower right quadrant 2 (low participation, high trust) where SH participation may not add value, at least not relative to the costs of implementing a participatory process and the upper left quadrant 4 (high participation, low trust), where social conflict and resource constraints have resulted in unstructured "wicked" problems that are not easy to resolve. To apply the split ladder, we made consensus judgments about the placement of each site along the axes of trust and participation at the start and end of the SAFER project based on synthesized site history, conditions, and engagement outcomes.

Table 3
Stakeholder identification and degree of engagement where 0 indicates present but not engaged and 1–5 refers to the degrees of engagement as described in Table 2. 'C' indicates SHs engaged by researchers collaborating with SAFER investigators and 'na' indicates SH group not present at the site.

Stakeholder category	LPC	LS	SGB	LdR	CG SM	SJR	MRW
Other Researchers	2	na	na	3	3	3	3
Residents	2	3	2	4	1	2	0
Local govt	2	3	1	4	C	2	3
Provincial/State Govt	2	na	na	4	C	2	3
National Govt	na	na	na	5	C	2	2
Lake/river Association(s)	na	4	na	4	C	2	2
Environmental groups	na	na	2	3	C	1	3
Recreational users	2	0	2	2	C	2	0
Seasonal residents	2	na	1	1	na	0	0
Tourism interests	2	3	1	2	C	0	2
Fishing interests	na	na	1	4	C	0	0
Farmers (crops)	na	1	0	1	C	0	na
Ranchers (livestock)	2	1	0	4	C	0	na
Forestry	2	na	na	0	C	2	1
Water/energy agencies	2	0	0	na	na	2	1
Transportation industry	0	na	na	na	C	0	na

3. Results

3.1. Research site assessments

The SAFER sites represent a diversity of inland watersheds (incorporating large river basins, coastal lagoons, lakes, and reservoirs) spread across a wide range of biogeographic, climatic, and socio-economic contexts (Table 1 and Appendix A). Although comparative research and risk assessments were the overarching goals of the network, it became evident that methodologies requiring SH participation were not practically replicable across all sites due to the prevailing differences in the socio-cultural contexts for engagement (i.e., capacity of the SHs to engage) as well as differences in the relative preparation and resources to start and maintain SH engagement activities across sites (i.e., capacities of research teams to engage). We find the split ladder helped characterize local variations in socio-environmental conditions that were not discernible in metrics of ES risk calculated from global and national scale data (see Harmon et al., 2018). For example, the adjusted Human Water Stress for the SAFER sites (given in Table 1), identifies the Ciénaga Grande de Santa Marta (CGSM) as most at risk but more notably differentiates sites along a north/south gradient reflecting greater national investments in water security but not necessarily conditions at the watershed scale. Starting with the southernmost site and progressing northward, the following case studies briefly summarize the SAFER sites including the history of SH engagement in water research and management, the research team at each site, and the engagement carried out during the SAFER project (Table 2) in terms of degrees of engagement. To compare inclusivity of engagement, we identify broad categories of watershed SHs and the degree to which they were engaged by site teams and collaborators (Table 3). This context is used to place each site on the split ladder (Fig. 2).

3.1.1. Lago Paloma Complex, Chile (LPC)

Representing the more pristine end of the socio-environmental gradient (Table 1 and Fig. 3 in Harmon et al., 2018), the LPC includes headwater streams, glacial lakes, and braided tributaries of the Rio Aysén in Chilean Patagonia. Although much of the watershed is within a National Forest Reserve, there is some degradation and soil erosion from land conversion to pasture. Still, conflicts over water resources and/or risks to ES are limited compared to other SAFER sites. There was occasional research conducted in the area prior to SAFER (e.g., Meier et al., 2013), establishing a baseline for contact with local SHs. The SAFER team at LPC consisted of two aquatic scientists in a region with limited university presence or other resources for recruiting or training students. At this essentially new and relatively remote research site, SAFER researchers initiated a range of engagement activities to interest, educate,

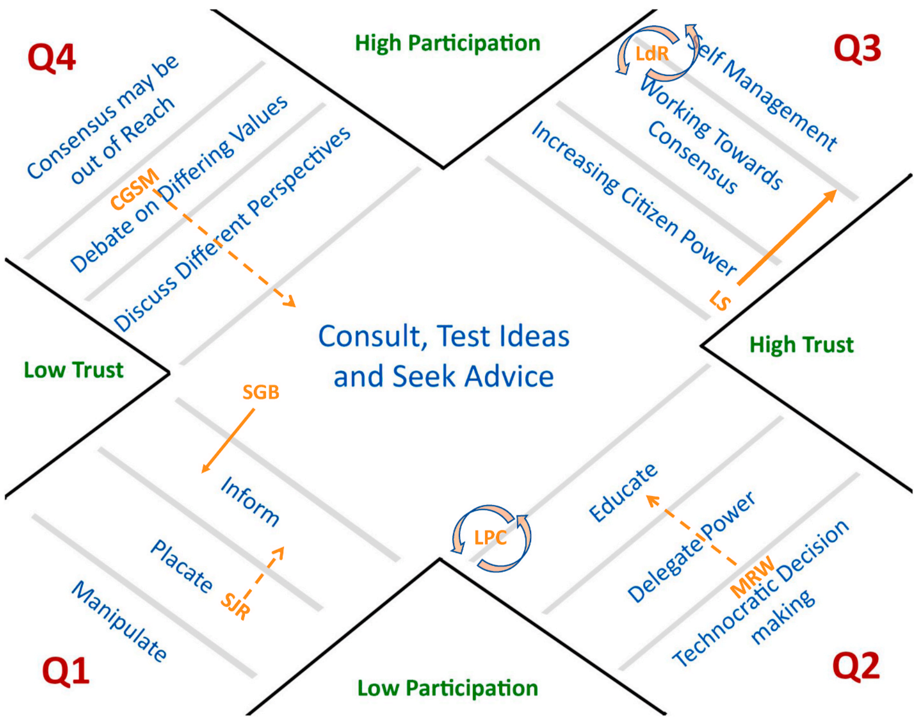

Fig. 2. Categorizations of conditions for engaging stakeholders at SAFER sites on the Split Ladder of Participation (after Hurlbert and Gupta, 2015). Four quadrants (Q1-Q4) are defined by gradients in trust (left to right) and participation (bottom to top). Solid lines indicate sites where SAFER scientists are leading stakeholder engagement efforts while dashed arrows indicate sites where the primary efforts to engage stakeholders are external to SAFER. Placements represent research consensus on site conditions at the start of the project and arrows indicate the direction in which engagement efforts were headed at the close of the project.

and build trust with SHs (Table 2). Engagement during SAFER has been largely informative and consultative, including communication with local residents on floodplain research and coordination with regional agencies on invasive species management (Table 3). Citizen science efforts, consisting of a lake monitoring program with instrumented buoys, interactions with rural schools, and development of educational materials (see Appendix C), have been implemented intermittently but proved difficult to sustain due to limited human resources and the challenges of remote and rural environments with low perceived risk to abundant water resources. Interviews of local and regional SHs about climate change perceptions by a collaborating graduate student, however, revealed important local knowledge of long-term changes in weather not captured by coarse meteorological monitoring in this mountainous region (Helman, 2015).

There were several reasons not to pursue high level SH engagement at LPC. A perceived power imbalance and complex diversity of SHs separated by both distance (geographically onsite vs. offsite SHs) and class (local rural SHs, national and international landowners, multinational energy companies with a major interest in water rights, and tourism sector) that make broad and simultaneous participation logistically challenging and potentially impractical. Furthermore, LPC lacks an imminent threat around which to formally engage SHs and sustain participation. Understanding threats to ES requires education on their very existence in this area. In terms of the split ladder (Fig. 2), governmental decision-making is offsite at the regional level with local SHs having little ability to influence such decisions. Given the absence of urgent threats, LPC researchers are maintaining low-level contact and monitoring, having adjusted the scale of operations (focusing on two individual lake basins and a small watershed contributing to local rural potable water supply). Engagement in research at this site remains in the exploratory middle of the split ladder as research activities have diversified to other sites with more emergent opportunities for SH work.

3.1.2. La Salada Lake, Argentina (LS)

La Salada, the smallest system in this study, is a shallow coastal lake used for economically-important tourism but threatened by diversions and runoff from neighboring agriculture. The research team at LS is multi-disciplinary, including climatology, oceanography, geology, environmental economics, limnology, biology, engineering and geography. Prior to the SAFER project, researchers from Instituto Argentino de Oceanografía began engaging SHs with the initiation of research at LS in 2011. A citizen science approach was used to deploy sensors on a lake buoy for research and education programs to increase local knowledge and enable ES protection (Smyth et al., 2016). Citizen science was first introduced to school children resulting in interactions among primary and secondary school teachers, students, and researchers, which has resulted in students learning about environmental research and participating in data collection (Smyth et al., 2016). During SAFER, the team set up a two-fold participatory study to identify and prioritize ecosystem services relevant to local SHs at LS following the ES risk assessment approach developed for Laguna de Rocha, Uruguay (see Lozoya et al., 2014), another SAFER site described below. The ES were pre-identified by a panel of physical and social scientists and then SHs were invited to community workshops where they were asked to individually rank the ES as they perceive them (Zilio et al., 2017). Maintenance of water quality received the highest priority by local SHs, likely due to the rapid proliferation of algae since 2008, which can impair economically-important tourism (Zilio et al., 2017). When asked to evaluate changes in ES provision between an unusually wet (2009) and dry (2015) year, only slight variations were reported, suggesting SHs are not yet perceiving differences, but this may also be the result of management to maintain a consistent lake water level despite the amount of rainfall.

Over several years, resident SHs around LS have evolved into a neighborhood lake association that now carries out many aspects of the lake's water quality research and management (excluding water diversion decisions made by the Corporation of the Colorado River Valley) (Zilio et al., 2017). The enthusiasm for lake conservation by most local SHs has enabled high levels of engagement in environmental research and management at LS. There is currently co-decisive engagement in research with a self-selected subset of SHs that, together with researchers, design and implement lake research and monitoring (Tables 2 and 3). The citizen science activity has been widely accepted by schools and students and significantly contributed to increasing the environmental awareness in the local community. With respect to the split ladder, both trust and participation increased at this site amongst the engaged SHs during SAFER (Fig. 2). The challenges at this site are moderately structured in that there is uncertainty in future water quantity and quality and limited resources for ecosystem-based management. While the SAFER team has achieved high levels of engagement with some SHs, there is a need to broaden participation to include agricultural SHs who are only minimally engaged at this time (Table 3). Their participation will likely be needed given the importance of water clarity for recreational tourism and the well-established adverse effects of agricultural runoff on water quality. Further eutrophication or a change in water level could shift this site from quadrant 3 to 4 on the split ladder in the future.

3.1.3. Sauce Grande Basin, Argentina (SGB)

Flows from the eastern slopes of the Sierra de la Ventana, the Sauce Grande river is divided by a large drinking water reservoir serving urban communities outside the watershed. Except for students, the research team for this site is the same as LS. The *Community-based Management of Environmental Challenges in Latin America* project, funded by the European Commission, was the first participatory research initiative in the lower SGB (London et al., 2012) and constituted the starting point to current research initiatives in the area. Due to the local perception that environmental conservation is inherently in opposition to agriculture, the research team anticipated and experienced difficulties engaging a large segment of relevant local SHs in water research. Separate workshops were planned for decision-making and non-decision making SHs with non-decision making SHs invited through a locally-active non-governmental organization, Ambiente Comarca. Several groups of off-site decision-making SHs were invited but did not participate in workshops. Many of the agriculturists also did not participate (see Zilio et al., 2019).

Based on overall low participation and preliminary workshop findings of skepticism and misunderstanding of climate data and projections for the region (indicating low trust in science), SGB is in Q1 of the split ladder. The initial goal of SH engagement, to replicate the participatory approach employed successfully at LS, was revised to first address the general lack of environmental/climate literacy in the region through informative engagement to build capacity for future participatory research. In recent years, national science policy in Argentina has shifted to emphasize integration between scientific results and policy applications. The scientific community was, therefore, newly encouraged to engage with communities to promote social learning and during the last five years, the relationships between some SH groups (farmers and environmental groups) and scientists has improved in SGB (from the perspective of researchers). Still, more work needs to be done to disseminate information to all SH groups before inclusive participatory research can proceed at this site.

3.1.4. Laguna de Rocha, Uruguay (LdR)

Laguna de Rocha (LdR) is a subtropical lagoon recognized as an UNESCO Biosphere Reserve and Ramsar Wetland of International Importance. LdR has a long and rich history of participatory management where SHs are organized into associations (e.g., fishermen association, cattle ranching society, tourism league) and represented on the Laguna de Rocha Local Advisory Committee (AC) initiated in the 1990s and legally formalized in 2010 when the lagoon was included in the National System of Protected Areas (Fanning, 2012). The AC has developed a management plan (Ministry of the Environment-MVOTMA Resolution 1030/2016) to address threats to the lagoon (Fanning, 2012). SHs participate in data collection and some fishers serve as rangers for the protected area. The multi-disciplinary research team at LdR was well-established at the start of the SAFER project and includes ecologists, hydrologists, anthropologists, sociologists, a lawyer and a land use planner. Researchers routinely exchange information with the AC and access SHs for interviews and other research modalities through the AC. Researchers conducted a participatory prioritization of ES and risk assessment (Lozoya et al., 2014) and planned an economic valuation study (Fanning, 2012) prior to SAFER.

Some of the challenges associated with engaging SHs in water research and management have been overcome with informative outreach about ES, local knowledge integration, and trust built over time (>10 years). The inclusion of LdR in Uruguay's nationally protected areas is considered an important outcome and metric of success for the participatory efforts at this site, as well as the participatory development of a protocol for the artificial breaching of the lagoon sand barrier (Conde et al., 2019). Despite accrued trust between scientists and SHs, differences remain with respect to climate change. LdR researchers find SHs generally perceive less climate risk than what is forecast by scientists (Lozoya et al., 2014). Overall, researchers leverage the successful participatory management structure to engage SHs broadly and to a relatively high degree (Tables 2 and 3). Despite efforts to engage equally, researchers reported fishers were more difficult to engage than other SHs. LdR researchers aim to increase engagement further by including SH vision and interests in the design of future research projects more than they have in past projects where SHs have generally played a consultative or collaborative role. The adaptive, participatory structure already in place at LdR reflects high trust and participation (Q3). During SAFER, LdR researchers were generally able to seek feedback and achieve consensus with other SHs as needed.

3.1.5. Ciénaga Grande de Santa Marta, Colombia (CGSM)

Colombia's largest coastal lagoon and mangrove ecosystem, CGSM, like LdR, is a Ramsar Wetland and UNESCO Biosphere Reserve. The production of bananas and palm oil are the predominant economic activities in the area, and irrigation needs are prioritized over other water uses, leaving local residents dependent upon fish production which is vulnerable during periods of low precipitation (Vilardy and González, 2011). Since the 1950s there has been social conflict over ES lost to degradation from reduced freshwater flows. In response, an ambitious restoration project was launched in 1992 by the national and regional government, with funding from the German government, aimed at restoring the hydrology and biotic resources, and promoting social development and institutional capacity (Botero and Salzwedel, 1999). The restoration project finished in 2001, but there has been a lack of maintenance in the hydraulic infrastructure and recent degradation of mangrove and fish resources due to increased salinity. Importantly, a lack of institutional response to the presence of illegal armed groups in the 1990s (guerrillas) and 2000s (paramilitaries) has exacerbated the environmental and social crises in the region (Vilardy and González, 2011). Governmental resources for ecosystem management were minimal and largely provided by international organizations with agendas that may not have aligned with local SHs (Ramirez, 2016). However, a large bloom event in 2014 led to renewed government action including the recent formation of a participatory initiative called ¡Escucha la Ciénaga! (la Ciénaga, 2018), where consensus is being sought but remains elusive (S. Vilardy pers. com.).

In addition to regional, national, and international institutional actors with diverging interests, there are two main SHs at CGSM, the local inhabitants living around the lagoon with little decision-making power and agricultural land owners who live outside the watershed. As at LPC, this dichotomy makes broad SH engagement difficult at this site. The SAFER team at CGSM consists of paleolimnologists, a physical geographer and a hydrologist. They have consulted and initiated collaboration with marine biologist Sandra Vilardy who has been engaged in ES valuation and other socio-environmental research in the watershed for more than ten years (e.g., Vilardy et al., 2012, 2011). Prior research on perceptions of ES and climate change risk show some divergence between scientists and the public. SHs identified more ES than scientists based on their local knowledge and use of the site. With respect to climate change, scientists warn of marine transgression due to sea level rise while locals attribute coastal erosion and increasing salinity to freshwater diversions upstream and do not identify climate change as a risk (Vilardy et al., 2012). Other researchers at INVEMAR (a Colombian institute for marine research) have developed citizen science initiatives to monitor fisheries with the local inhabitants. Lacking expertise and resources for high level SH engagement, the SAFER team at this site has engaged informally with SHs during the course of research and focused on developing collaboration with researchers external to SAFER that have already established trust with SHs to provide social perspectives and information relevant to SAFER's research questions. Based on the work prior and external to SAFER, CGSM can be characterized as low trust and minimal participation on the split ladder (Fig. 2). Efforts to achieve higher degrees of participation at this site would likely only serve to push it further into the upper left Q4, the domain of "wicked problems".

3.1.6. San Joaquin River, USA (SJR)

Historically, the San Joaquin River (SJR) and its tributaries flowed from the Sierra Nevada Mountains through the Central Valley to the Sacramento-San Joaquin delta. Water scarcity in SJR is a long-standing regional issue. Institutional SHs from the public and private sectors with both economic and non-economic interests are well-identified and included in the on-going, legally-mandated water management efforts. Upstream of the delta, a largely technocratic restoration effort is managed by San Joaquin River Restoration Program (SJRRP) under the 2009 San Joaquin River Restoration Settlement Act. SJRRP's two goals are to restore and maintain fish populations in the main stem of the river and reduce adverse water supply impacts. These goals represent consensus reached through long legal battles amongst SHs that will be difficult, if not impossible, to achieve, given the climatological constraints on the water supply. This duality creates a complex setting for engaging potentially fatigued SH in water research.

The SAFER team at SJR consists of one environmental engineering and one economics professor and graduate students, and is primarily focused on modeling hydrology and water quality with existing and future water management constraints and climate scenarios. There is not a well-integrated social scientist on the SJR team. However, the prominence of the tensions around the SJR means that the social/political issues are well-known and widely discussed in the press and beyond. With SAFER grant resources disproportionately distributed to South American sites, there was little capacity for high level engagement at SJR. SAFER researchers are engaged with federal agencies and some water utilities (primarily for acquiring data for models), bringing a water engineering perspective to the board of the SJR Conservation and Trust, and conducting informative outreach activities with watershed advocacy groups, recreational users and other interested citizens (Tables 2 and 3). Most of those attending educational workshops have an a priori interest in the environment, suggesting strategies are needed to broaden the scope of SH engagement to include other relevant SH groups, but based upon the site history that is likely to be challenging.

With competing demands for very scarce water, SJR has long been a site of conflict resulting generally in low trust amongst SHs. During the extended legal battle between environmental groups and regulatory agencies, there was high participation that could be characterized as *debate diverging values* (a rung in Q4), but today, with a consensus legal settlement in place and legislation to guide and fund implementation, SJR is managed more or less technocratically by the SJRRP with contributions from organized SH groups. Despite the agreement amongst key SH groups, the scientific reality is that in dry years, there will likely be insufficient water to meet both irrigation and restoration demands and therefore we are characterizing SJR as being in a state of *placation* in Q1 (Fig. 2). With limited expertise and resources to carry out participatory engagement with a fatigued (and potentially disillusioned) SH community spread over a large geographic area, the site team conducted informative engagement with interested SH and participated consultatively with institutional SH engaged in conservation, restoration, and education to help build realistic expectations of water resource challenges (Tables 2 and 3). Finally, the state has required SH driven negotiations to manage California's largely unadjudicated groundwater basins. This will add an additional level of complexity to the management of the SJR and the engagement of SHs that are multiple, layered, and polarized, creating the possibility that participatory conditions will return to Q4.

3.1.7. Muskoka River Watershed, Canada (MRW)

The Muskoka River originates in Ontario's Algonquin Provincial Park highlands and flows through a formerly glaciated landscape with abundant lakes and wetlands into Lake Huron. Outdoor-oriented tourism is currently the primary economic driver of the region with the summer population of 81,907 exceeding the region's 60,599 permanent residents (District of Muskoka, 2018). Thus, there are strong economic incentives to maintain environmental quality but also recreational and other activities that can lead to degradation. The region has a developed environmental civic society that includes several lake associations, non-governmental groups, and an active watershed council, the Muskoka Watershed Council. The watershed plan, created in 2006, calls for engaging SHs to voice concerns regarding the local freshwater resources and increase support for environmental conservation (Veale, 2010). The large percentage of seasonal residents may present challenges to participatory research and management (Veale, 2010). The SAFER team at MRW consisted of a government research limnologist and a Ph.D. student focused on ecological modeling. As with SJR, there was no social scientist integrated into the research team and limited resources for SAFER-specific engagement of SHs. Researchers informally identified relevant SHs and utilized information gathered from SHs for other projects to inform SAFER research at MRW. Overall, engagement was primarily informative and consultative due to a lack of time and expertise to develop, lead, and analyze participatory activities at this site. With no urgent conflicts over water resources, MRW is managed primarily technocratically in an environment of moderate to high trust in institutions and moderate engagement of self-organizing SH groups and is therefore placed in Q2 on the split ladder with engagement efforts emphasizing education of both SH and researchers (Fig. 2). Capacity building for participatory research is important at this site where emerging threats, such as increasing algae blooms, are fostering greater participation (e.g., formation of an algae working group across lake associations).

3.2. Applying the split ladder

We used the split ladder to visualize differences in site context and explain variations in the degree and breadth of SH engagement across sites. The split ladder categorizes sites based on trust (low to high from left to right) and participation (low to high from bottom to top) in resource management/governance. The placements on the split ladder reflect consensus judgments amongst SAFER researchers about the conditions for SH participation at each site. The four sites with on-going management efforts were in the four different quadrants of the split ladder at the start of SAFER (Fig. 2). We located SJR in Q1 (low participation & low trust) to convey the expectation that SHs may be fatigued by long legal battles or content with recent signs of success in recovering salmon. Hydro-climatic modeling suggests these successes will be difficult to sustain over the long-term given the economic and climatological constraints on the region's water resources. Education and outreach were therefore the predominant mode of engagement. At MRW, a tourism-based region of Canada with abundant water resources and low population pressure, there is largely technocratic management with relatively high trust in governance (Q2), mainly due to the absence of evident conflict among water users. In addition, generating and sustaining SH participation is somewhat complicated by the large seasonal population in the region. SAFER researchers at MRW have also focused on educational engagement, particularly around emerging threats where calls for participation in decision making are likely to increase over time. CGSM is a highly impacted tropical lagoon where efforts to collectively manage have been difficult to sustain given long-term political instability and SH inequality, thus characterized by high participation but low trust (Q4). At this site, SAFER researchers are proceeding slowly, respecting and engaging with researchers who have established trust with SHs over time. At LdR where there is high trust and participation (Q3), the SAFER project contributed to advancing the ongoing adaptive co-management approach that has evolved over decades of communication and collaboration. In some ways, LdR represents a participatory model for other sites in the network to emulate, while recognizing the timelines and resources required to do so are generally beyond the scope of a single grant.

At the other three sites (LS, SGB, LPC), there had been less management and engagement prior to SAFER. These sites, by default, started closer to the middle of the ladder and moved out in different directions due to a combination of factors (Fig. 2). The research team is largely the same for sites in Argentina (LS, SGB). Adapting the LdR approach, this well-integrated multidisciplinary team effectively engaged the community around a small, tourism-oriented lake to take responsibility for water quality monitoring and maintenance (Q3). They had less success, however, in engaging SHs in the agriculturally-dominated SGB (Q1). At the latter site, researchers' emphasis remained on informative engagement to build trust and scientific literacy after preliminary results showed widespread mis-understandings about climate risks to local water resources (Zilio et al., 2019). At LPC, there is low population density, near-pristine water resources and tourism based on fly fishing. Although water resources are economically important at this site, the lack of urgent threats presents challenges to creating and sustaining engagement in water research or participation in risk assessments to get ahead of potential problems. Furthermore, participation in resource management is culturally not the norm in Chile (Q2). At this site, researchers have focused on listening to SHs and making educational and outreach materials specific to the local aquatic ecosystem to facilitate social learning (see Appendix C).

As suggested by Hurlbert and Gupta (2015), we find the split ladder has potential as a "diagnostic" tool. The distribution of sites in the quadrants informs the nature of engagement that is appropriate. Sites on the left (Q1 and Q4) lack sufficient trust for highly participatory methodologies. At sites with low trust, researchers may first have to work towards building or rebuilding local trust in science and/or policy, and integrating local knowledge and concerns into research activities *before* participatory research methodologies can be applied. In polarized situations, such as SJR and CGSM, this can take time, special expertise, and significant resource commitments that were beyond the scope of this grant. These are also the geographically largest of the SAFER watersheds. It may be prudent and necessary to conduct comparative research and engagement in representative sub-watersheds to keep the scale of the effort comparable to other sites. For sites in Q2, highly participatory engagement may be hard to establish or sustain if SHs are not empowered or concerned with decision making. At remote sites like LPC, with no urgent threat or culture of engagement, we argue informative and consultative engagement is the best practice.

In the interest of maintaining SH willingness to participate as a public good, researchers should be cautious about implementing highly participatory methodologies for sites outside Q3. Communities that have experienced successful SH engagement in the past may be more willing to participate in future projects, as in the case of LdR and LS. For sites in Q1, Q2, and Q4, highly collaborative engagement activities may be counterproductive, creating resistance, mistrust, disillusionment, or conflict amongst SHs. We suggest educational, informative, and consultative activities that aim towards the neutral center of the split ladder are advisable. Given the trajectory of water resource management towards participation and integration, it is important for researchers to engage SHs in an informed way that encourages positive outcomes for the SHs, not just the researchers (Barreteau et al., 2010). By promoting consideration of the context for engagement, the quadrants of the split ladder may prove a useful tool in determining sites that are suitable for comparative engagement methodologies. We recommend the split ladder Hurlbert and Gupta (2015) to help research networks understand differences in the social dimensions of the research sites and plan engagement activities accordingly and adaptively.

3.3. Barriers to engagement

The sociocultural context and capacities for engaging SHs in research varied across the SAFER sites at the start of the project in a manner that precluded the replication of research methodologies requiring SH participation across the network. Instead, researchers at each site engaged SHs on a site by site basis with informal knowledge transfer about practice and progress across the network during meetings and site visits. Categorizing the engagement activities by degree on the traditional ladder of participation (Table 2), there was informative and consultative engagement to promote scientific literacy and enable some local knowledge integration into research across all sites. Only a few of the sites, however, were able to engage in participatory (collaborative and higher) activities with local SHs by the end of the project (Tables 2 and 3). The highest levels and broadest SH engagement occurred at LdR where SAFER researchers were already involved in a long-standing, adaptive ecosystem co-management program with established trust and a participatory ES risk assessment already underway at the start of SAFER (Lozoya et al., 2014). Following and adapting the ES risk assessment approach used at LdR (Lozoya et al., 2014), high levels of engagement were achieved at LS in a relatively short period of time (Zilio et al., 2017). LS is in an area economicallydependent upon recreational tourism and is by far the smallest water body in this study. Overall, conditions were favorable for engagement at LS with both willing SHs and a well-resourced multidisciplinary team in place. At other sites, smaller research teams encountered more complicated or unfavorable conditions for engaging SHs in research. Some teams (CGSM, MRW, SJR) sought collaboration with social scientists already engaging SHs in the watershed to bring social perspectives to SAFER research and risk assessments. This approach respects the notion that engagement is a public good that needs to be maintained but may limit the application of cross-site methodologies.

With the split ladder framework, we identified several external factors influencing the degree and breadth of engagement across sites. SH willingness to participate was influenced by the predominant economic activities in the watershed, perceived threats to water resources, and history and culture of engagement, including the relative empowerment of the SHs in decision making. There was some form of agricultural production or forestry in all the study watersheds. At sites with large-scale irrigated agriculture (SJR, CGSM, SGB) ES are already challenging to maintain. In the face of climate change, water scarcity is likely to intensify at these sites as well as at LS. Water scarcity creates difficult conditions for inclusive engagement. Water quality is also impacted by agriculture with eutrophication and increasing harmful algal blooms reported at several sites (LS, LdR, CGSM). Agricultural SHs were difficult to engage in water research across sites, a situation that merits focused attention and new strategies in subsequent studies given the importance of agricultural SHs to sustainable water management. In contrast, at sites where tourism is economically important (MRW, LS, LPC, LdR), water quality is a high priority for SHs who derive economic and other benefits from maintaining and/or improving aquatic environments. Across sites, researchers noted SHs were willing to engage with research teams when threats to water were visible, either from algae blooms or diminishing water availability. When threats to ES were not apparent, SHs were less interested in collaborating with researchers and engagement was difficult to maintain (LPC, SGB). At LS with both tourism and agriculture, the threat of declining water quality appeared to be an important motivator of the SHs engaged by researchers.

At sites with complicated histories of unsatisfactory engagement or no empowerment in decision making (SJR, CGSM, LPC), researchers had to engage with caution. Social inequalities amongst SHs were noted as a barrier at LPC, LdR, CGSM, SGB and SJR. Particularly at sites in South America, there is a dichotomy between (disempowered) local SHs dependent upon the ecosystem for livelihoods and off-site landowners or government entities with decision-making authority in the watershed. These power differences complicate broad and integrated SH engagement. Differences in power and voice among SHs is also an important consideration at SJR where the economic interests of agriculture have tended to prevail and SH fatigue is likely.

In addition to the variety of challenges presented by the gradient of socio-environmental conditions in the SAFER network, there were also differences in the capacities of the site teams to engage SHs and build trust along the way. When surveyed at the close of the project, the top three barriers to SH engagement identified by SAFER researchers pertained to internal team capacity: disciplinary expertise, experience, time, and people to effectively engage SHs and collect pertinent social data (Fig. 3). Lack of social science collaborators was a closely related barrier at many sites. At the remote LPC with no pressing social conflict, finding a social scientist willing to participate was difficult and constrained the capacity for social science data collection. Despite barriers encountered, 77% of SAFER researchers reported they plan to continue to engage SHs in research and 93% reported greater appreciation for methodologies outside their discipline at the end of the project. Enabling comparative socio-hydrological research will require more training and resources for building well-integrated, balanced, and productive multidisciplinary teams, as discussed below.

4. Discussion

Integrated understanding of socio-hydrologic systems is a challenging but important goal for supporting water security (Sivapalan et al., 2012; Xu et al., 2018) and sustaining aquatic ES (Baron et al., 2002). However, it is important to recognize that research methodologies requiring SH participation are not as readily replicated across sites as are studies of a geological or ecological nature. Human behavior, including willingness to participate in research activities, is highly contingent and cultural (Enserink et al., 2007; Reed, 2008; Rowe and Frewer, 2004). The SAFER network coalesced around the overarching goal of comparing risks to water resources across broad hydrologic and social gradients. A quantitative analysis using available climatic, watershed, and socioeconomic indicators to characterize threats to aquatic ES across SAFER sites noted the potential limits of national-scale governance and

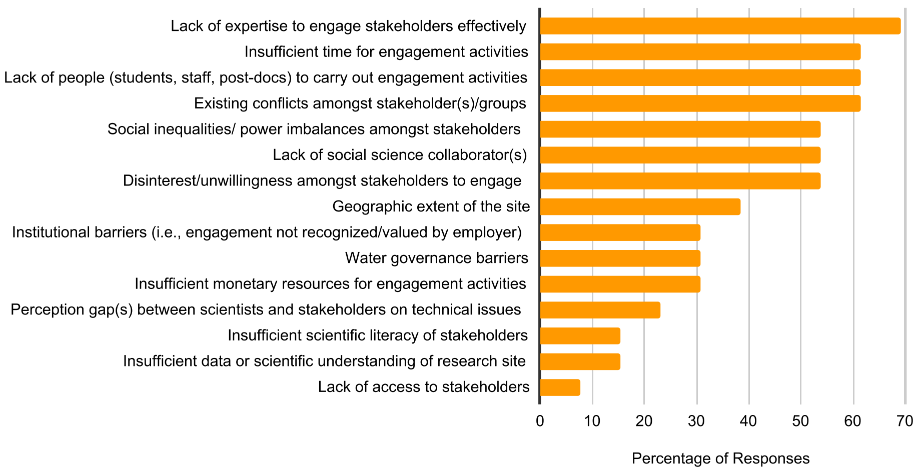

Fig. 3. Barriers to stakeholder engagement identified by SAFER researchers.

socioeconomic indicators to reflect the socio-environmental conditions at the local watershed scale, particularly in rural regions (Harmon et al., 2018). Here we show that in practice there are many barriers to engaging SHs and generating relevant social data at the watershed scale in a manner that is comparable across sites. We know local culture and governance patterns impact the success of participatory processes but the implications for the design of participatory experiments across research networks remains unclear.

The SAFER sites reflect some of the diversity of freshwater ecosystems across the Americas from socio-economic, ecological, and climatological perspectives (Harmon et al., 2018). Ranging from relatively unimpacted LPC in Chile where engagement in research and resource management is uncommon to SJR in California where climate change is exacerbating long-standing social conflict over scarce water resources, this diversity in sites presents challenges and opportunities in conducting comparative research including SHs. We found the split ladder of participation to be a useful tool for considering the history of engagement, trust, and otherwise "diagnosing" the conditions for SH engagement in research and risk assessment. It is important for multi-disciplinary research networks to expect site-to-site differences when planning comparative methodologies that require SH participation and recruit and integrate researchers from relevant social science disciplines into site teams (Ban et al., 2013; Bennett et al., 2017; Xu et al., 2018).

4.1. *Lessons learned*

Our qualitative analysis indicates that at several sites in the SAFER network, high degrees of engagement were not practical or appropriate in the near-term, especially in places where there is existing low trust (SJR, CGSM) or no tradition of civic engagement activities in resource management and research (LPC). At such sites, informative and consultative engagement to facilitate knowledge integration and social capacity building are, we argue, appropriate and necessary first steps to enable meaningful participation in the future and avoid negative outcomes. Several site teams emphasized the need to simply listen to SHs, especially those disempowered by decision-making structures. The split ladder framework led us to the identification of two main lessons learned related to the transition from low-trust to high-trust environments where desirable participatory outcomes are more likely.

1. Evaluate and adapt research engagement activities to local site conditions

Viewing SH willingness to participate as a "public good" to be cultivated by the (self-identified) participatory research community means that project success is determined, at least in this regard, by the state of mind of the participants at the end of the project; if participants are happy, it is a positive outcome and vice versa. Unfortunately, it can be difficult for researchers to know which of the many participatory mechanisms will yield satisfied SHs and/or meaningful results. There is little known about transferability of approaches across sites or how to select and adapt an existing framework to a particular site in order to achieve the benefits of participatory research while avoiding the pitfalls (Barreteau et al., 2010; Blackstock et al., 2007; Enserink et al., 2007). Furthermore, the cultural and socioeconomic dimensions of successful participation are not fully understood nor are the conditions that lead to favorable social learning and better decision making through participatory methods versus other less costly and time consuming approaches (Hurlbert and Gupta, 2015; von Korff et al., 2010; Reed, 2008). The timelines for responsibly engaging and developing relationships with SHs are unknown and difficult to predict a priori. This creates a challenge for the replication of SH-dependent methodologies that should be approached with careful planning utilizing the split ladder or alternative framework that seeks to elucidate the conditions for engagement to the entire research team (not just the social scientists). Implementation should be done in an adaptive manner with explicit evaluations and adjustments at key points in the process. Researchers should ensure that disempowered SHs are included to reduce marginalization and promote the integration of previously missing perspectives into the collective understanding (von Korff et al., 2010; Luyet et al., 2012; Sterling et al., 2017). The integration of previously sidelined SH narratives can allow relevant parties to identify groups that exhibit high vulnerability or other barriers to participation and enable the creation of targeted policies that equalize representation (Luyet et al., 2012; Sterling et al., 2017). We conclude that it is important for research networks to consider site to site variability in the context for interacting with SHs across research sites early on and to develop comparative research objectives, timelines, and adaptive, cyclic frameworks that are sufficiently flexible to allow for SH engagement to develop constructively at each site.

2. Build research teams for socio-hydrological research

The challenge of recruiting and integrating social scientists into ecosystem science projects is not unique to SAFER. The need to reframe research questions and practice to attract and retain social science collaborators has been noted by others studying conservation biology, water, and other complex human-natural systems (e.g., Ban et al., 2013; Bennett et al., 2017; Fischer et al., 2015; Xu et al., 2018). To consolidate lessons learned and improve guidance about the appropriateness and transferability of engagement approaches, there is a need for greater participation of social scientists of many varieties to answer interdisciplinary research questions and evaluate effectiveness of participatory approaches. We recommend flexible and adaptive approaches that treat engagement as an on-going, cyclical process, that is periodically evaluated by both researchers and SHs (Mott Lacroix and Megdal, 2016; Sterling et al., 2017) and not constrained to a particular grant timeline. For both new and pre-existing research sites, different conditions for SH engagement should be anticipated and carefully considered in the design of participatory methodologies to avoid negative outcomes for SHs and researchers. The SAFER network experience reinforces previous findings that engagement is site specific and time is needed to build trust and facilitate positive SH interactions. Replication is challenging. Research networks, therefore, need more time and resources to learn to communicate effectively (Read et al., 2016), understand site differences and develop, to the extent practical, common protocols for engaging SHs in a way that enables robust comparisons while building public trust in participation. Additional investments in tools and strategies, evaluation protocols, and interdisciplinary team training are needed to enable the participatory SH engagement in research and is required to answer pressing questions about the coupled human-natural water cycle (Xu et al., 2018).

Engaging stakeholders in water research is critically important for generating policy-relevant science and building resilience in aquatic ecosystems. However, SH participation is also an uncertain enterprise that is inherently resource and time intensive with some methodologies requiring specialized expertise that may not be available at all research sites. As research networks advance questions about complex socio-hydrological systems that call for SH participation, effective cross-disciplinary communication and careful planning are required to balance the goal of positive SH outcomes with other research interests on grant-determined timelines. Proactive application of tools like the split ladder can help research teams and networks find this balance by clarifying differences in the conditions for engaging SHs across sites and deploying resources and methodologies accordingly.

Author contribution statement

The study was conceptualized by RLS, LB, SP, MIZ, BR, MAHC, DC, TH, NH, JE, GMEP, MCP, JAR and MV at a SAFER PI meeting in April 2016; qualitative data was provided by BR, MIZ, AA, MAHC, DC, TH, NH, JE, JPL, GMEP, MCP, JAR, MV; case study analysis was conducted by UF, RLS, MS, and LB; Writing-Original Draft Preparation by RLS, UF, MS, LB, SP, BR; Writing-Review & Editing by all authors. Funding Acquisition and project administration by GMEP, MV, DC, TH, JE, MCP, BR, JAR, MIZ.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Socio-hydrological context and climate projections for each site

Lago Paloma Complex, Chile (LPC)

The LPC includes oligotrophic glacial-tectonic lakes, mountain streams, and braided rivers in the headwaters of the Rio Blanco sub-watershed of the Rio Aysén, Chilean Patagonia. Climate is temperate sub-Antarctic, ranging from deciduous to evergreen temperate rain forest biomes along very short distances. Climatic information and climate change projections are both confounded by uncertainty for this topographically varied terrain (Lenaerts et al., 2014; Vera et al., 2006); 30% reductions in precipitation have been observed at the mouth of the Aysén watershed, and changes in seasonality are expected (Aravena and Luckman, 2009) with anomalously moderate temperature increases (Garreaud et al., 2013). The region has experienced decreased snowpack according to general local observations (Helman, 2015; Pérez et al., 2018) and lakes rivers and streams have all seen record low water levels (B. Reid pers. obs) following convergence of cyclic hydrologic drivers El Niño, Antarctic Oscillation (Garreaud, 2018). High water clarity driven by stable lake flows, together with access from urban areas provides regionally-important tourism and recreational services with economic benefits for some local residents. The site has extremely low population density, significant intact headwaters and (mapped in Astorga et al., 2018), falling within National Forest Reserve. However, wildfires during recent colonization (1940–60s) has resulted in massive soil loss and permanent vegetation change for valley walls, and conversion of valleys to pasture. Other threats include firewood cutting, spread of invasive species, and potential hydropower development, the latter is conflictive in the sense of governance (Bauer, 1997) and conflict over water rights.

La Salada Lake, Argentina (LS)

La Salada Lake is a shallow, saline lake located in the south of the Buenos Aires Province, 57 km from the coast and 14 m above sea level. The lake has no surface outlet and is naturally mesotrophic. In terms of water quality, it responds quickly to environmental and anthropogenic stresses due to its large surface area to volume ratio (Alfonso et al., 2015). It is in a semi-arid climate, experiencing decadal variation in wet and dry periods and an increase of 0.7 °C in average annual temperature over the last 50 years (Aliaga et al., 2016). The watershed is sparsely populated and water-oriented tourism (fishing, swimming, water sports, bird watching) is the main economic driver followed by cattle ranching and agriculture requiring irrigation and fertilizer application. Given tourism is the main economic driver around LS, water resources are important to local SHs. The Corporation of the Colorado River Valley, the authority responsible for managing water for irrigation, currently controls the lake level through two gate-controlled channels from the Colorado river such that the lake level is maintained for recreational activities over irrigation needs (Zilio et al., 2017). There is concern amongst researchers and SHs that additional water control during droughts and floods could exacerbate lake drying and lakeshore erosion, respectively. Eutrophication from agricultural runoff is also a concern as this could lead to a decline in recreational activity in response to blooms (Smyth et al., 2016).

Sauce Grande Basin, Argentina (SGB)

The Sauce Grande river originates from the eastern slopes of the Sierra de la Ventana Range in the southwest of the Buenos Aires Province, Argentina and flows into the Atlantic Ocean. The regional climate is temperate and characterized by wet and dry periods (Aliaga et al., 2017; Bohn et al., 2011). The Paso de las Piedras reservoir was built in the 1970s to supply drinking water to Bahía Blanca and Punta Alta cities (nearly 360,000 inhabitants, both located outside the basin). The reservoir divides the watershed into the upper basin (highlands to the dam), the middle basin, (reservoir to Sauce Grande shallow lake), and the lower basin (lake to the estuary where the river discharges into the Atlantic Ocean) (Gil, 2010; Zilio et al., 2019). Different natural environments (mountains, plains, lakes, and estuary) offer several opportunities for tourism across the watershed. Climate projections predict a slow but steady increase in temperature and precipitation fluctuations in the area (Aliaga et al., 2016). The basin provides a range of ecosystem services including irrigation, drinking water, sewage disposal, and various recreational activities like sport fishing and swimming. Prominent economic activities of the region include agriculture and tourism. Production is mainly staple crops (soybeans, corn, wheat, and sunflower) and livestock (cattle and sheep) with recent diversification to include olive growing, winemaking, and aromatic crops (Zilio et al., 2019). In the Buenos Aires province, the Water Code (Law 12.257/99) establishes a regime of protection, conservation, and management conducted by the provincial Water Authority. Users must obtain a permit from the Water Authority to carry out surface or underground extraction (Zilio et al., 2019). Nevertheless, population growth and recurring droughts together have greatly increased water demands on the site and have seriously impacted the local water resources (Casado et al., 2016).

Laguna de Rocha, Uruguay (LdR)

Laguna de Rocha (LdR) is a subtropical lagoon on the Atlantic coast and arguably the most studied aquatic ecosystem in Uruguay. The northern area of the lagoon is dominated by freshwater discharge from the watershed and the southern area is highly influenced by the ocean through a channel that is opened periodically, both naturally and artificially, and results in salinity ranging from freshwater to marine conditions. Its unique geological characteristics and complex physiochemical make-up result in an area of high primary productivity (Alonso et al., 2013; Bonilla et al., 2006). LdR has been a UNESCO Biosphere Reserve since 1976 and was added to Ramsar Convention on Wetlands of International Importance in 2015. The most important ES in the region are artisanal fish and natural shrimp production, erosion and flood protection, water quality maintenance, and recreational and cultural activities (Fanning, 2012; Lozoya et al., 2014; Nin, 2013). Since the 1990s, land use in the LdR watershed has been dominated by cattle grazing and intensive agriculture. In the coastal zone, urbanization for tourism is increasing, with private property invading natural and fragile areas (i.e. sand barrier). The population has grown to about 30,000 permanent inhabitants and an additional 40,000 summer residents. Climatologically, LdR is now experiencing major storm surges and changes in wind patterns driving flooding of coastal villages, and coastal erosion (Fanning, 2012; Lozoya et al., 2014). ES are under threat from increasing temperature, precipitation, and sea level rise (Fanning, 2012; Lozoya et al., 2014; Nin, 2013), as well as eutrophication, unplanned tourism development, artificial water level regulation, and a failure to fully implement the local management plan.

Ciénaga Grande de Santa Marta, Colombia (CGSM)

The Ciénaga Grande de Santa Marta (CGSM) is part of Colombia's largest coastal lagoon system, with its extensive mangrove ecosystem earning it status in the Ramsar Convention on Wetlands in 1998 and as a UNESCO Biosphere Reserve designation in 2000. Located in the tropics, this site experiences high seasonal and interannual variation in precipitation associated with the El Niño – Southern Oscillation (ENSO) and low frequency drivers (i.e. quasi-decadal) associated with atmospheric pressure gradients and sea surface temperature in the Atlantic and Pacific Oceans (Restrepo et al., 2019). In addition to the high biodiversity value, the lagoon provides economically important ES supporting commercial fishing and tourism. Natural freshwater inputs into the lagoon have long been modified to irrigate plantations owned largely by wealthy, non-local SH. There are many human stressors impacting both the quality and the quantity of freshwater in the lagoon. Freshwater diversions have historically led to salinity increases associated with declines in socioeconomically-important fish and mollusk production. Increasing population and intensive agricultural activity in the adjacent watersheds have caused hyper-eutrophication leading to cyanobacteria blooms, oxygen depletion and fish kills (Botero and Mancera, 1996; Hernández and Gocke, 1990; Polania et al., 2001). Climate projections for the region point to lower precipitation and less runoff from the basin (Blanco and Viloria, 2006). This, together with projected sea level rise, will likely lead to further salinization of the CGSM, which is currently more saline than it has been in ca. 5300 years based upon the paleorecord (Velez et al., 2014).

San Joaquin River, USA (SJR)

The San Joaquin River (SJR) and its tributaries originate in the Southern Sierra Nevada Mountains and flow in a westerly direction through California's Central Valley (CV) and north into the San Francisco Bay via the Sacramento-San Joaquin delta. The climate is generally characterized by hot, dry summers and cooler, wetter but highly variable winters with a precipitation gradient in the watershed that ranges from near 170 cm/yr in the mountains to 15 cm/yr in the valley. The natural river-wetland complex that historically supported Chinook salmon and other migratory fish species has been heavily altered by dam construction and water diversions such that the river runs dry in the CV in all but the wettest years (Bay-Delta Fish & Wildlife Office, n.d.). River flows are controlled by several multi-purpose reservoirs located along the mountain front and used to produce hydropower and supply water to the over $10 billion agricultural industry in the lower valley. In addition to commercial uses, the upper reservoirs are used for recreational activities (boating, rafting, fishing). A legal settlement reached in 2006 mandates restoration of water flows for the historic spring-run of Chinook salmon and other fish species in the SJR while minimizing impacts to commercial users (Bay-Delta Fish & Wildlife Office; San Joaquin River Restoration Program, n.d.). The SJR regional climate outlook suggests that increases in the frequency and intensity of water scarcity issues are likely in the future (Cayan et al., 2009; Hayhoe et al., 2004). Models suggest +1 to 2 °C by year 2050 and + 2 to 6 °C by year 2100 with more intense variability during the summer (Jackson et al., 2012). Modeled outcomes and observations regarding precipitation in the Southern Sierra Nevada Mountains suggest that there may be similar amounts of precipitation in the future, but more rain and less snow, which is expected to lead to earlier depletion of the annual snowpack and increasingly scarce water for summer and fall irrigation seasons. The gap between water demand and surface water supply in the SJR basin has historically been filled with groundwater and has resulted in severely over-drafted aquifers (Famiglietti et al., 2011). Warmer drier weather will reduce flows and elevate the water temperature regime, endangering the Chinook salmon restoration effort (Myrick and Cech, 2001).

Muskoka River Watershed (MRW)

The Muskoka River originates in the Algonquin Provincial Park highlands in central Ontario, Canada and flows through a formerly glaciated landscape with abundant lakes and wetlands. Located at the southern limit of the boreal ecozone, the climate is cool, wet, and seasonally variable. The Muskoka River and the many lakes and wetlands in its watershed provide many freshwater ES including supplying drinking water, tourism and recreational opportunities, generating hydropower, receiving wastewater, mitigating flood events and maintaining biodiversity in natural habitats. Many of these ES rely on maintenance of water quality, which is overall in good condition currently but threatened by land use change, salinization, and extreme weather events. Climate projections for the region vary with modeling scenarios, but median temperature change is predicted to be +2–3 °C by 2050 with substantial changes in the timing of precipitation but not the total amount (Yao et al., 2013; Wang et al., 2014, 2015).

Appendix B. Understanding engagement practices

Table B1
Questions developed and answered by each SAFER site team for this cross-site stakeholder analysis.

Code	Site Context
A1	What are the local human and climate change impacts on your watershed/water body?
A2	How does the local community utilize this water body?
A3	How did you define risk at your research site?
A4	What are the human-induced and climate change risks to this site?
A5	How developed/common is civil society/SH engagement in environmental management around your site? (World Bank defines civil society as "the wide array of non-governmental and not-for-profit organizations that have a presence in public life, expressing the interests and values of their members or others, based on ethical, cultural, political, scientific, religious or philanthropic considerations.")
A6	Are there social scientists involved in your site/project? If yes, specify their contribution.
	SH Engagement Process

(continued on next page)

Table B1 (*continued*)

Code	Site Context
B1	Who are the SHs at your site? How did you go about identifying potential SHs for your site?
B2	How did you approach these SHs? How/why did you prioritize amongst different types of SHs (e.g., local residents, watershed/environmental groups, government officials)
B3	When in your scientific study of this water body did you begin to approach SHs? (e.g., before deciding upon a study site, before any data collection, after buoy deployment)
B4	What challenges have you encountered in trying to engage SHs in your research/risk assessment?
B5	Have you (or others at your site) evaluated perceptions of local SHs of climate change risk? If yes, to what extent are these perceptions the same or different from the perceptions of the scientists?
B6	Have you identified/evaluated the ecosystem services of your site? If yes, how did you do so? (e.g., scientific expert opinion, in collaboration with community SHs)
B7	Have any ecosystem service valuation studies been conducted at your site?
B8	Are there citizen scientists active at your site? (citizen scientists are community members that have been trained by scientists to collect scientific data)
B9	Have you determined any mitigation approaches/solutions? If yes, how were these approaches determined (e.g., by scientific experts, in collaboration with SHs)?
	Reflection and Thinking Ahead
C1	What has worked at your site to yield useful information for freshwater risk assessment? Explain the lesson(s) learned.
C2	What have you tried with respect to SH engagement that hasn't worked?
C3	If you were to start over, what would you do differently to engage SHs?
C4	What do you plan to do next with respect to SH engagement?
C5	Have your definitions of risk and SH changed as a result of this project? If yes, explain how so.

Appendix C. Science as an Education and Outreach Feedback Process: A Case study from Chile

Stakeholder outreach at the LPC site (Chile) began as series of informal interaction between researchers and land owners that pre-date the SAFER project, consisting of requests for access to field sites, general conversation about the research and findings, and occasional requests for logistic support like student housing, transportation or guide services (Table C1). Formalization of the SH process began with a proposal, driven by researchers, for a potential designation as zone free off aquatic invasive species. The proposal was intended as a policy model and novel approach to controlling the spread of the invasive diatom *D. geminata*, and the site was chosen based on hydrologic isolation and value for commercial fly fishing (Reid et al., 2012). Despite an informal declaration with signage at the site's watershed boundaries, no resources were available for implementation (only for areas already affected by invasive species). This result, together with the range and social and geographic complexity of identified stakeholders, and lack of evident resource conflicts over short to medium time scales, led to a series of coupled research and education efforts implemented at this site, and also within a broader geographic area. These include a climate change perception study (Helman, 2015) and a lake monitoring initiative that included both citizen science and educational objectives. The latter proved to be more productive: starting with a field and classroom based science illustration workshop directed toward local rural schools, illustrations of local plants and animals by students aged 5–15 were included in the first chapter of an educational book on lakes and climate change (Figure C1). This chapter, highlighting the elements that were felt to be the easiest bridge or connection with the broader theme of lake ecosystems, is followed up by subsequent chapters incrementing levels of complexity: a focus on organisms is followed by examples of ecological patterns and interactions; this in turn followed by chapters on the geographic template, climate drivers of lakes, effects of human land use in the watershed. This in turn finally enabling a basic discussion of how lakes may be affected by climate change, and the importance of monitoring. Wherever possible observations by local residents (e.g. climate perception study), and local examples, were used in the book. This approach, on one hand, constitutes a form of active intervention, it was felt to be a necessary step in terms of the difficulty in defining problems, conflicts, risks, or areas where scientific investigation might contribute toward resolving any of these. Hence the SH outreach process may not be independent of the education process, meanwhile education as local interpretation of global generalizations (often the product of scientific investigation elsewhere) may be considered an extension of communication of scientific results.

Table C1
Stakeholder engagement over time.

Year	Activity
2007	First research contact with local residents (PhD project)
2009–2010	First sustained research activities (Fondecyt project).
2013	Proposal for Aquatic Invasive free zone;
2013	Development of site-based guide to the natural and human history, incorporating both Interviews with local residents and results of previous scientific research;
2014	Climate change perception survey;
2015	Demonstration of meteorological station and mini-buoy in aquarium, rural schools and community;
2015	Painting of buoys with science or environmental message;
2016 -	Workshops on scientific illustration, with field and classroom components
2017–1018	Student illustrations incorporated in educational materials: *"Lagos como Sentinelas de Cambio Climatico"*

Fig. C1. 2016 Workshops on scientific illustration, with field observations (upper left) and classroom activities (lower left) contributing to a field guide and educational material on local lake.

References

Alfonso, M.B., Vitale, A.J., Menéndez, M.C., Perillo, V.L., Piccolo, M.C., Perillo, G.M.E., 2015. Estimation of ecosystem metabolism from diel oxygen technique in a saline shallow lake: La Salada (Argentina). Hydrobiologia 752, 223–237. https://doi.org/10.1007/s10750-014-2092-1.

Aliaga, V.S., Ferrelli, F., Alberdi-Algarañaz, E.D., Bohn, V.Y., Piccolo, M.C., 2016. Distribución y variabilidad de la precipitación en la Región Pampeana, Argentina. Cuadernos de Investigación Geográfica 42, 261. https://doi.org/10.18172/cig.2867.

Aliaga, V.S., Ferrelli, F., Piccolo, M.C., 2017. Regionalization of climate over the Argentine pampas: climate in the pampas. Int. J. Climatol. 37, 1237–1247. https://doi.org/10.1002/joc.5079.

Alonso, C., Piccini, C., Unrein, F., Bertoglio, F., Conde, D., Pernthaler, J., 2013. Environmental dynamics as a structuring factor for microbial carbon utilization in a subtropical coastal lagoon. Front. Microbiol. 4 https://doi.org/10.3389/fmicb.2013.00014.

Aravena, J.-C., Luckman, B.H., 2009. Spatio-temporal rainfall patterns in southern south America. Int. J. Climatol. 29, 2106–2120. https://doi.org/10.1002/joc.1761.

Arnstein, S.R., 1969. A ladder of citizen participation. J. Am. Inst. Plan. 35, 216–224. https://doi.org/10.1080/01944366908977225.

Astorga, A., Moreno, P., Reid, B., 2018. Watersheds and trees fall together: an analysis of intact forested watersheds in southern Patagonia (41–56° S). Forests 9, 385. https://doi.org/10.3390/f9070385.

Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., et al., 2013. A social–ecological approach to conservation planning: embedding social considerations. Front. Ecol. Environ. 11, 194–202. https://doi.org/10.1890/110205.

Baron, J.S., Poff, N.L., Angermeier, P.L., Dahm, C.N., Gleick, P.H., Hairston, N.G., et al., 2002. Meeting ecological and societal needs for freshwater. Ecol. Appl. 12, 1247–1260.

Barreteau, O., Bots, P.W.G., Daniell, K.A., 2010. A framework for clarifying participation in participatory research to prevent its rejection for the wrong reasons. Ecol. Soc. 15 https://doi.org/10.5751/ES-03186-150201.

Bauer, C.J., 1997. Bringing water markets down to earth: the political economy of water rights in Chile, 1976–1995. World Dev. 25, 639–656. https://doi.org/10.1016/S0305-750X(96)00128-3.

Bennett, N.J., Roth, R., Klain, S.C., Chan, K.M.A., Clark, D.A., Cullman, G., et al., 2017. Mainstreaming the social sciences in conservation: mainstreaming the social sciences. Conserv. Biol. 31, 56–66. https://doi.org/10.1111/cobi.12788.

Blackstock, K.L., Kelly, G.J., Horsey, B.L., 2007. Developing and applying a framework to evaluate participatory research for sustainability. Ecol. Econ. 60, 726–742. https://doi.org/10.1016/j.ecolecon.2006.05.014.

Blanco, J.A., Viloria, E.A., 2006. ENSO and salinity changes in the Ciénaga Grande de Santa Marta coastal lagoon system, Colombian Caribbean. Estuarine. Coastal and Shelf Science 66, 157–167.

Bohn, V.Y., Piccolo, M.C., Perillo, G.M.E., 2011. Análisis de los periodos secos y húmedos en el sudoeste de la provincia de Buenos Aires (Argentina) 11, 14.

Bohn, V.Y., Delgado, A.L., Piccolo, M.C., Perillo, G.M.E., 2016. Assessment of climate variability and land use effect on shallow lakes in temperate plains of Argentina. Environmental Earth Sciences 75. https://doi.org/10.1007/s12665-016-5569-6.

Bonilla, S., Conde, D., Aubriot, L., Rodríguez-Gallego, L., Piccini, C., Meerhoff, E., et al., 2006. Procesos estructuradores de las comunidades biológicas en lagunas costeras de Uruguay. Bases Para La Conservación y El Manejo de La Costa Uruguaya 611–630.

Botero, L., Mancera, J.E., 1996. Síntesis de los cambios de origen antrópico ocurridos en los últimos 40 años en la Ciénaga Grande de Santa Marta (Colombia). Rev Acad Colomb Cienc 20, 465–474.

Botero, L., Salzwedel, H., 1999. Rehabilitation of the Ciénaga Grande de Santa Marta, a mangrove-estuarine system in the caribbean coast of Colombia. Ocean Coast Manag. 42, 243–256.

Brendel, A.S., Bohn, V.Y., Piccolo, M.C., 2017. In: Climatic Variability Effects on the Vegetation State and Water Coverage in a Watershed of Temperate Climate (Argentina), vol. 40. Anuário do Instituto de Geociências - UFRJ, pp. 5–16. https://doi.org/10.11137/2017_2_05_16.

Casado, A., Peiry, J.-L., Campo, A.M., 2016. Geomorphic and vegetation changes in a meandering dryland river regulated by a large dam, Sauce Grande River, Argentina. Geomorphology 268, 21–34. https://doi.org/10.1016/j.geomorph.2016.05.036.

Cayan, D.R., Tyree, M., Dettinger, M.D., León, H., Hugo, G., Das, T., et al., 2009. Climate change scenarios and sea level rise estimates for California 2008 Climate Change Scenarios Assessment.

Conde, D., Solari, S., de Álava, D., Rodríguez-Gallego, L., Verrastro, N., Chreties, C., et al., 2019. Ecological and social basis for the development of a sand barrier breaching model in Laguna de Rocha, Uruguay. Estuarine. Coastal and Shelf Science 219, 300–316. https://doi.org/10.1016/j.ecss.2019.02.003.

Correa-Metrio, A., Vélez, M.I., Escobar, J., St-Jacques, J.-M., López-Pérez, M., Curtis, J., et al., 2016. Mid-elevation ecosystems of Panama: future uncertainties in light of past global climatic variability: a thousand years of environmental variability in Panama. J. Quat. Sci. 31, 731–740. https://doi.org/10.1002/jqs.2899.

District Municipality of Muskoka, 2018. Population. https://www.muskoka.on.ca/en/work-and-invest/Population.aspx. (Accessed 17 September 2018).

Enserink, B., Patel, M., Kranz, N., Maestu, J., 2007. Cultural factors as Co-determinants of participation in River basin management. Ecol. Soc. 12 https://doi.org/10.5751/ES-02096-120224.

Famiglietti, J.S., Lo, M., Ho, S.L., Bethune, J., Anderson, K.J., Syed, T.H., et al., 2011. Satellites measure recent rates of groundwater depletion in California's Central Valley: Central Valley groundwater depletion. Geophys. Res. Lett. 38 https://doi.org/10.1029/2010GL046442.

Fanning, A.L., 2012. Assessing monetary valuation methodologies for estimating the impacts of climate change in the Laguna de Rocha (Uruguay). Dalhousie University.

Fischer, J., Gardner, T.A., Bennett, E.M., Balvanera, P., Biggs, R., Carpenter, S., et al., 2015. Advancing sustainability through mainstreaming a social–ecological systems perspective. Curr. Opin. Environ. Sustain. 14, 144–149. https://doi.org/10.1016/j.cosust.2015.06.002.

Garreaud, R.D., 2018. Record-breaking climate anomalies lead to severe drought and environmental disruption in western Patagonia in 2016. Clim. Res. 74, 217–229.

Garreaud, R., Lopez, P., Minvielle, M., Rojas, M., 2013. Large-scale control on the patagonian climate. J. Clim. 26, 215–230. https://doi.org/10.1175/JCLI-D-12-00001.1.

Gil, V., 2010. In: Hidrogeomorfología de la cuenca alta del río Sauce Grande aplicada alpeligro de crecidas. Universidad Nacional de Sur.

Harmon, T.C., Smyth, R.L., Chandra, S., Conde, D., Dhungel, R., Escobar, J., et al., 2018. Socioeconomic and environmental proxies for comparing freshwater ecosystem service threats across international sites: a diagnostic approach. Water 10, 1578. https://doi.org/10.3390/w10111578.

Hayhoe, K., Cayan, D., Field, C.B., Frumhoff, P.C., Maurer, E.P., Miller, N.L., et al., 2004. Emissions pathways, climate change, and impacts on California. Proc. Natl. Acad. Sci. Unit. States Am. 101, 12422–12427.

Helman, M.I., 2015. In: Perceptions of Climate Change and Water Governance Vulnerability in the Aysén Region of Chile. University of Montana.

Hernández, C.A., Gocke, K., 1990. Productividad primaria en la Ciénaga Grande de Santa Marta, Colombia. An Inst Invest Mar Punta Betín 19, 101–119.

Hoyos, N., Correa-Metrio, A., Jepsen, S.M., Wemple, B., Valencia, S., Marsik, M., et al., 2019. Modeling streamflow response to persistent drought in a coastal tropical mountainous watershed, Sierra Nevada de Santa Marta, Colombia. Water 11, 94. https://doi.org/10.3390/w11010094.

Hurlbert, M., Gupta, J., 2015. The split ladder of participation: a diagnostic, strategic, and evaluation tool to assess when participation is necessary. Environ. Sci. Pol. 50, 100–113. https://doi.org/10.1016/j.envsci.2015.01.011.

Jackson, L.E., Pulleman, M.M., Brussaard, L., Bawa, K.S., Brown, G.G., Cardoso, I.M., et al., 2012. Social-ecological and regional adaptation of agrobiodiversity management across a global set of research regions. Global Environ. Change 22, 623–639. https://doi.org/10.1016/j.gloenvcha.2012.05.002.

Jepsen, S.M., Harmon, T.C., Ficklin, D.L., Molotch, N.P., Guan, B., 2018. Evapotranspiration sensitivity to air temperature across a snow-influenced watershed: space-for-time substitution versus integrated watershed modeling. J. Hydrol. 556, 645–659. https://doi.org/10.1016/j.jhydrol.2017.11.042.

Kueffer, C., Underwood, E., Hirsch Hadorn, G., Holderegger, R., Lehning, M., Pohl, C., et al., 2012. Enabling effective problem-oriented research for sustainable development. Ecol. Soc. 17 https://doi.org/10.5751/ES-05045-170408.

la Ciénaga, ¡Escucha, 2018. Comienzan los diálogos para recuperar la Ciénaga Grande de Santa Marta. n.d. http://www.minambiente.gov.co/index.php/noticias/3402-escucha-la-cienaga-comienzan-los-dialogos-para-recuperar-la-cienaga-grande-de-santa-marta.

Lenaerts, J.T.M., van den Broeke, M.R., van Wessem, J.M., van de Berg, W.J., van Meijgaard, E., van Ulft, L.H., et al., 2014. Extreme precipitation and climate gradients in Patagonia revealed by high-resolution regional atmospheric climate modeling. J. Clim. 27, 4607–4621. https://doi.org/10.1175/JCLI-D-13-00579.1.

London, S., Recalde, M., Rojas, M., 2012. Stakeholder vision on social-ecological system situation in Argentina case study. COMET-LA. https://helvia.uco.es/xmlui/handle/10396/9993.

Lozoya, J.P., Conde, D., Asmus, M., Polette, M., Píriz, C., Martins, F., et al., 2014. Linking social perceptionsocial perception and risk analysis to assess vulnerability of coastal socio-ecological systems to climate change in atlantic south America. In: Leal Filho, W. (Ed.), Handbook of Climate Change Adaptation. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1–22. https://doi.org/10.1007/978-3-642-40455-9_105-1.

Luyet, V., Schlaepfer, R., Parlange, M.B., Buttler, A., 2012. A framework to implement Stakeholder participation in environmental projects. J. Environ. Manag. 111, 213–219. https://doi.org/10.1016/j.jenvman.2012.06.026.

Meerhoff, E., Rodríguez-Gallego, L., Giménez, L., Muniz, P., Conde, D., 2013. Spatial patterns of macrofaunal community structure in coastal lagoons of Uruguay. Mar. Ecol. Prog. Ser. 492, 97–110. https://doi.org/10.3354/meps10472.

Megdal, S., Eden, S., Shamir, E., 2017. Water governance, stakeholder engagement, and sustainable water resources management. Water 9, 190. https://doi.org/10.3390/w9030190.

Meier, C.I., Reid, B.L., Sandoval, O., 2013. Effects of the invasive plant Lupinus polyphyllus on vertical accretion of fine sediment and nutrient availability in bars of the gravel-bed Paloma river. Limnologica Ecol. Manag. Inland Waters 43, 381–387. https://doi.org/10.1016/j.limno.2013.05.004.

Mott Lacroix, K., Megdal, S., 2016. Explore, synthesize, and repeat: unraveling complex water management issues through the stakeholder engagement wheel. Water 8, 118. https://doi.org/10.3390/w8040118.

Myrick, C.A., Cech, J.J., 2001. In: Temperature Effects on Chinook Salmon and Steelhead: a Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum, 01-1. http://www.sfei.org/modelingforum/.

National Academies of Sciences, Engineering, and Medicine, 2017. Communicating Science Effectively: A Research Agenda. National Academies Press, Washington, D. C.. https://doi.org/10.17226/23674

Nin, M., 2013. In: Mapeo de servicios ecosistémicos en la cuenca de la Laguna de Rocha como un insumo para la planificación territorial. Universidad de la República.

Pérez, T., Mattar, C., Fuster, R., 2018. Decrease in snow cover over the Aysén river catchment in Patagonia, Chile. Water 10, 619. https://doi.org/10.3390/w10050619.

Polania, J., Santos-Martínez, A., Mancera-Pineda, J.E., Arboleda, L.B., 2001. The coastal lagoon Ciénaga Grande de Santa Marta, Colombia. In: Coastal Marine Ecosystems of Latin America. Springer, pp. 33–45.

Ramirez, L.F., 2016. Marine protected areas in Colombia: advances in conservation and barriers for effective governance. Ocean Coast Manag. 125, 49–62. https://doi.org/10.1016/j.ocecoaman.2016.03.005.

Read, E.K., O'Rourke, M., Hong, G.S., Hanson, P.C., Winslow, L.A., Crowley, S., et al., 2016. Building the team for team science. Ecosphere 7, e01291. https://doi.org/10.1002/ecs2.1291.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biol. Conserv. 141, 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014.

Reid, B.L., Hernández, K.L., Frangópulos, M., Bauer, G., Lorca, M., Kilroy, C., et al., 2012. The invasion of the freshwater diatom *Didymosphenia geminata* in Patagonia: prospects, strategies, and implications for biosecurity of invasive microorganisms in continental waters: *didymosphenia* invasion in South America. Conserv. Lett. 5, 432–440. https://doi.org/10.1111/j.1755-263X.2012.00264.x.

Restrepo, J.C., Higgins, A., Escobar, J., Ospino, S., Hoyos, N., 2019. Contribution of low-frequency climatic–oceanic oscillations to streamflow variability in small, coastal rivers of the Sierra Nevada de Santa Marta (Colombia). Hydrol. Earth Syst. Sci. 23, 2379–2400. https://doi.org/10.5194/hess-23-2379-2019.

Rodríguez-Gallego, L., Achkar, M., Defeo, O., Vidal, L., Meerhoff, E., Conde, D., 2017. Effects of land use changes on eutrophication indicators in five coastal lagoons of the Southwestern Atlantic Ocean. Estuar. Coast Shelf Sci. 188, 116–126. https://doi.org/10.1016/j.ecss.2017.02.010.

Rowe, G., Frewer, L.J., 2004. Evaluating public-participation exercises: a research agenda. Sci. Technol. Hum. Val. 29, 512–556. https://doi.org/10.1177/0162243903259197.

Sivapalan, M., Savenije, H.H.G., Blöschl, G., 2012. Socio-hydrology: a new science of people and water: invited commentary. Hydrol. Process. 26, 1270–1276. https://doi.org/10.1002/hyp.8426.

Smyth, R.L., Caruso, A., Borre, L., Zhu, G., Zhu, M., Hetherington, A.L., et al., 2016. High-frequency lake data benefit society through broader engagement with stakeholders: a synthesis of GLEON data use survey and member experiences. Inland Waters 6, 555–564. https://doi.org/10.1080/IW-6.4.894.

Stafford, S.G., Bartels, D.M., Begay-Campbell, S., Bubier, J.L., Crittenden, J.C., Cutter, S.L., et al., 2010. Now is the time for action: transitions and tipping points in complex environmental systems. Environ. Sci. Pol. Sustain. Dev. 52, 38–45. https://doi.org/10.1080/00139150903481882.

Sterling, E.J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., et al., 2017. Assessing the evidence for stakeholder engagement in biodiversity conservation. Biol. Conserv. 209, 159–171. https://doi.org/10.1016/j.biocon.2017.02.008.

Tengö, M., Brondizio, E.S., Elmqvist, T., Malmer, P., Spierenburg, M., 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. Ambio 43, 579–591. https://doi.org/10.1007/s13280-014-0501-3.

Thomas, G., 2011. A typology for the case study in social science following a review of definition, discourse, and structure. Qual. Inq. 17, 511–521. https://doi.org/10.1177/1077800411409884.

Trimble, M., Berkes, F., 2013. Participatory research towards co-management: lessons from artisanal fisheries in coastal Uruguay. J. Environ. Manag. 128, 768–778. https://doi.org/10.1016/j.jenvman.2013.06.032.

Veale, B.J., 2010. In: Assessing the Influence and Effectiveness of Watershed Report Cards on Watershed Management: a Study of Watershed Organizations in Canada. University of Waterloo.

Velez, M.I., Escobar, J., Brenner, M., Rangel, O., Betancourt, A., Jaramillo, A.J., et al., 2014. Middle to late Holocene relative sea level rise, climate variability and environmental change along the Colombian Caribbean coast. Holocene 24, 898–907. https://doi.org/10.1177/0959683614534740.

Vera, C., Silvestri, G., Liebmann, B., González, P., 2006. Climate change scenarios for seasonal precipitation in South America from IPCC-AR4 models. Geophys. Res. Lett. 33 https://doi.org/10.1029/2006GL025759.

Vilardy, S.P., González, J.A. (Eds.), 2011. Repensando la Ciénaga: nuevas miradas y estrategias para la sostenibilidad en la Ciénaga Grande de Santa Marta. Santa Marta, Col. Univ. del Magdalena [u.a.].

Vilardy, S.P., González, J.A., Martín-López, B., Montes, C., 2011. Relationships between hydrological regime and ecosystem services supply in a Caribbean coastal wetland: a social-ecological approach. Hydrol. Sci. J. 56, 1423–1435. https://doi.org/10.1080/02626667.2011.631497.

Vilardy, S.P., González, J.A., Martín-López, B., Oteros-Rozas, E., Montes, C., 2012. Los servicios de los ecosistemas de la Reserva de Biosfera Ciénaga Grande de Santa Marta. Revibec: Rev. Iberoam. Economía Ecológica 19, 66–83.

Villamizar, S.R., Pai, H., Butler, C.A., Harmon, T.C., 2014. Transverse spatiotemporal variability of lowland river properties and effects on metabolic rate estimates: transverse gradients of metabolic rate. Water Resour. Res. 50, 482–493. https://doi.org/10.1002/2013WR014245.

von Korff, Y., d'Aquino, P., Daniell, K.A., Bijlsma, R., 2010. Designing participation processes for water management and beyond. Ecol. Soc. 15 https://doi.org/10.5751/ES-03329-150301.

Wang, X., Huang, G., Lin, Q., Liu, J., 2014. High-resolution probabilistic projections of temperature changes over Ontario, Canada. J. Clim. 27, 5259–5284.

Wang, X., Huang, G., Lin, Q., Nie, X., Liu, J., 2015. High-resolution temperature and precipitation projections over Ontario, Canada: a coupled dynamical-statistical approach: high-Resolution Temperature and Precipitation Projections. Q. J. R. Meteorol. Soc. 141, 1137–1146. https://doi.org/10.1002/qj.2421.

Xu, L., Gober, P., Wheater, H.S., Kajikawa, Y., 2018. Reframing socio-hydrological research to include a social science perspective. J. Hydrol. 563, 76–83. https://doi.org/10.1016/j.jhydrol.2018.05.061.

Xue, X., Schoen, M.E., Ma, X., Cissy), Hawkins, T.R., Ashbolt, N.J., Cashdollar, J., et al., 2015. Critical insights for a sustainability framework to address integrated community water services: technical metrics and approaches. Water Res. 77, 155–169. https://doi.org/10.1016/j.watres.2015.03.017.

Yao, H., Rusak, J.A., Paterson, A.M., Somers, K.M., Mackay, M., Girard, R., et al., 2013. The interplay of local and regional factors in generating temporal changes in the ice phenology of Dickie Lake, south-central Ontario, Canada. Inland Waters 3, 1–14. https://doi.org/10.5268/IW-3.1.517.

Young, J.C., Jordan, A., Searle K, R., Butler, A., Chapman D, S., Simmons, P., et al., 2013. Does stakeholder involvement really benefit biodiversity conservation? Biol. Conserv. 158, 359–370. https://doi.org/10.1016/j.biocon.2012.08.018.

Zilio, M.I., Alfonso, M.B., Ferrelli, F., Perillo, G.M.E., Piccolo, M.C., 2017. Ecosystem services provision, tourism and climate variability in shallow lakes: the case of La Salada, Buenos Aires, Argentina. Tourism Manag. 62, 208–217. https://doi.org/10.1016/j.tourman.2017.04.008.

Zilio, M.I., Seitz, C., Scordo, F., Gil, V., Zapperi, P., Costilla, P., et al., 2019. Is collaborative management always possible? The case of Sauce Grande River Basin, Argentina. Int. J. River Basin Manag. 17, 251–261. https://doi.org/10.1080/15715124.2018.1546727.

https://www.fws.gov/sfbaydelta/Fisheries/SanJoaquinRiverRestoration/Index.htm, 2017–. (Accessed 16 September 2018).